LIBRARY OF FUNCTIONS FOR CONTACT DETECTION WITH APPLICATIONS IN BIOMECHANICS

FINAL PRESENTATION

LEBiom's Final Project

Supervised by Prof. Daniel Simões Lopes

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MOTIVATION

VARIETY OF FIELDS

Collision Detection can be used in: astronomy, physics, molecular geometry, electromagnetics, fluid mechanics…

BIOMEDICAL RELEVANCE

Simulating foot-ground contact[1] & virtual reality-based training system for needle micromanipulation[2].

MULTIPLE VIRTUAL APPLICATIONS

Virtual reality training, video games, rapid digital prototyping, and robotics simulation make use of **Collision Detection** and **Shortest Distance calculations**.

[1] “A superellipsoid-plane model for simulating footground contact during human gait” (Lopes et al., 2015)
[2] “Multisensory learning cues using analytical collision detection between needle and a tube” (Wang et al., 2004)

CHALLENGE

Collision detection has attracted the attention of researchers for decades in the field of computer graphics, robot motion planning, computer-aided design...

&

A large number of successful algorithms have been proposed and applied.

BUT

! **A compilation of these solutions is lacking.**

AND

There's a need to increase the computational performance of already existing algorithms.

GOAL

What we proposed to do:

1. Review the literature.
2. Compile the functions into a systematized library.
3. Create a game in Unity to apply and interact with the library created.
4. Develop a small Biomechanical simulation.

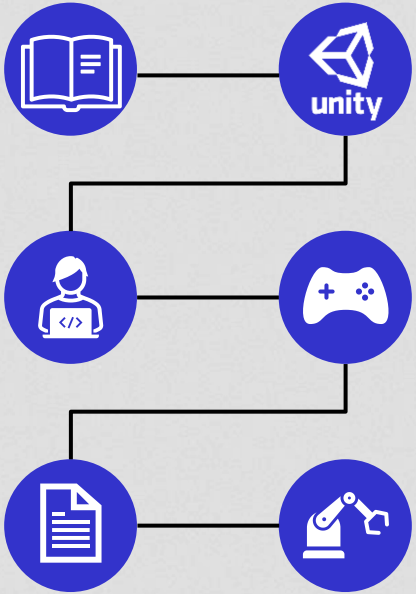
STRATEGY

STEP 1

Literature review.

STEP 2

Get familiar with Unity and C# scripting.



STEP 3

Development of a library of functions.

STEP 4

Development of a Unity game implementing the created library.

STEP 5

Publish the code and write down a paper on "state-of-the-art“.

STEP 6

Implementation of case studies in movement biomechanics.

LITERATURE REVIEW

30 references

- **5** books
- **20** papers
- **5** online repositories

CLOSEST DISTANCE TABLE 2D (26 contact pairs)

Contact Pairs	References	Used References	Specific Location/Equation
2D			
Point-Line	Scheneider, J.P., Eberly, D. H., "Distance in 2D", "Point to Linear Component", "Point to Line". Geometric Tools for Computer Graphics. Morgan Kaufamann Publishers. 2003. p 190-191.		
Point-Ray	Scheneider, J.P., Eberly, D. H., "Distance in 2D", "Point to Linear Component", "Point to Ray". Geometric Tools for Computer Graphics. Morgan Kaufamann Publishers. 2003. p 191-192.		
Point-Segment	1. Scheneider, J.P., Eberly, D. H., "Distance in 2D", "Point to Linear Component", "Point to Segment". Geometric Tools for Computer Graphics. Morgan Kaufamann Publishers. 2003. p 192-193. 2. Ericson C., "Basic Primitive Tests", "Closest-point Computations", "Closest Point on Line Segment to Point ". Real-Time Collision Detection. Elsevier Inc., 2005. p. 127-129		
Point-Polyline	Scheneider, J.P., Eberly, D. H., "Distance in 2D", "Point to Polyline". Geometric Tools for Computer Graphics. Morgan Kaufamann Publishers. 2003. p 194-		

Closest Distance 2D table

(**26** contact pairs)

Closest Distance 3D table

(**36** contact pairs)

CLOSEST DISTANCE TABLE 3D (36 contact pairs)

Contact Pairs	References
3D	
Point-Linear Component	Scheneider, J.P., Eberly, D. H., "Distance in 3D", "Point to Linear Component". Geometric Tools for Computer Graphics. Morgan Kaufamann Publishers. 2003. p 365-367
Point-Line-Segment	Scheneider, J.P., Eberly, D. H., "Distance in 3D", "Point to Linear Component", "Point to Ray or Line Segment". Geometric Tools for Computer Graphics. Morgan Kaufamann Publishers. 2003. p 367-369.
Point-Ray	Scheneider, J.P., Eberly, D. H., "Distance in 3D", "Point to Linear Component", "Point to Ray or Line Segment". Geometric Tools for Computer Graphics. Morgan Kaufamann Publishers. 2003. p 367-369.
Point-Polyline	Scheneider, J.P., Eberly, D. H., "Distance in 3D", "Point to Linear Component", "Point to Polyline". Geometric Tools for Computer Graphics. Morgan Kaufamann Publishers. 2003. p 369-374.
Point-Plane	1. Scheneider, J.P., Eberly, D. H., "Distance in 3D", "Point to Planar Component", "Point to Plane". Geometric Tools for Computer Graphics. Morgan Kaufamann Publishers. 2003. p 374-376. 2. Christer Ericson, "Basic Primitive Tests", "Closest-point Computations", "Closest Point on Plane to Point ". Real-Time Collision Detection. Elsevier Inc., 2005. p. 126-127
	1. Scheneider, J.P., Eberly, D. H., "Distance in 3D", "Point to Planar Component", "Point to Triangle". Geometric Tools for Computer Graphics. Morgan Kaufamann Publishers. 2003. p 376-382

Link dos vídeos: https://drive.google.com/drive/folders/1qskfVW6yp6mhC9OsbgQmolKIkwbyKSa3?usp=sharing

Collision Table 2D: (61 contact pairs)

Contact Pairs	References	Used Reference(s)	Specific Locatio Equation
2D			
Point-Point	1. Schwarzl, T. "Collision Detection: Point-Point Collision". 2D Game Collision Detection: An introduction to clashing geometry in games. CreateSpace Independent Publishing Platform, 2012. p. 29 2. jeffThompson, "CollisionDetection/CodeExamples/PointPoint at master · jeffThompson/CollisionDetection," GitHub, Dec. 12, 2018		
Point-Line	1. Schwarzl, T. "Collision Detection: Point-Line Collision". 2D Game Collision Detection: An introduction to clashing geometry in games. CreateSpace Independent Publishing Platform, 2012. p. 50 2. jeffThompson, "CollisionDetection/CodeExamples/LinePoint at master · jeffThompson/CollisionDetection," GitHub, Dec. 12, 2018		
Point-Line-Segment	Schwarzl, T. "Collision Detection: Point-Line-Segment Collision". 2D Game Collision Detection: An introduction to clashing geometry in games. CreateSpace Independent Publishing Platform, 2012. p. 51		

Collision Detection 3D table

(**89** contact pairs)

COLLISION TABLE 3D (89 contact pairs)

Contact Pairs	References
3D	
Line-Triangle	Scheneider, J.P., Eberly, D. H., "Intersection in 3D", "Linear Components and Planar Components", "Linear Components and Tools for Computer Graphics. Morgan Kaufamann Publishers. 2003. p 485-488.
Line-Polygon	Scheneider, J.P., Eberly, D. H., "Intersection in 3D", "Linear Components and Planar Components", "Linear Components and Tools for Computer Graphics. Morgan Kaufamann Publishers. 2003. p 488-491.
Line-Disk	Scheneider, J.P., Eberly, D. H., "Intersection in 3D", "Linear Components and Planar Components", "Linear Component and for Computer Graphics. Morgan Kaufamann Publishers. 2003. p 491-493.
Line-Polyhedra	Scheneider, J.P., Eberly, D. H., "Intersection in 3D", "Linear Components and Polyhedra". Geometric Tools for Computer Gra Kaufamann Publishers. 2003. p 493-498.
Line-Quadric Surface	Scheneider, J.P., Eberly, D. H., "Intersection in 3D", "Linear Components and Quadric Surfaces", "General Quadric Surfaces". Computer Graphics. Morgan Kaufamann Publishers. 2003. p 499-501.
Line-Sphere	Scheneider, J.P., Eberly, D. H., "Intersection in 3D", "Linear Components and Quadric Surfaces", "Linear Components and Sp for Computer Graphics. Morgan Kaufamann Publishers. 2003. p 501-503.
Line-Ellipsoid	Scheneider, J.P., Eberly, D. H., "Intersection in 3D", "Linear Components and Quadric Surfaces", "Linear Components and an

Collision Detection 2D table

(**61** contact pairs)

Link dos vídeos: https://drive.google.com/drive/folders/1I9xZX9wEYRHl_SiFW3PhfKdwdP6w5jJW?usp=sharing

CHOSEN PRIMITIVES

SHORTEST DISTANCE

Primitives in two and three dimensions:

- Point-Point;
- Point-Line Segment;
- Line Segment-Line Segment;
- Point-Circle/Sphere;
- Line Segment-Circle/Sphere;
- Circle/Sphere-Circle/Sphere.

COLLISION DETECTION

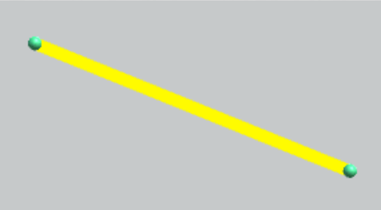
Primitives in two and three dimensions:

- AABB-AABB;
- OBB-OBB.

Primitives in three dimensions:

- Point-AABB;
- Point-Sphere;
- Sphere-AABB;
- Sphere-Sphere.

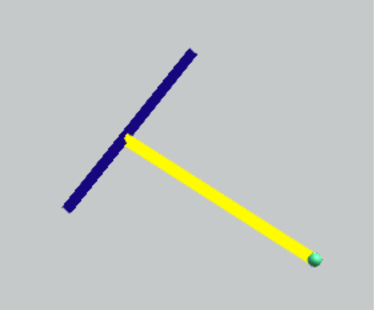
POINT-POINT



Given two points $\mathbf{P_1}$ and $\mathbf{P_2}$,

$$\boldsymbol{Closest\ Distance}: \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

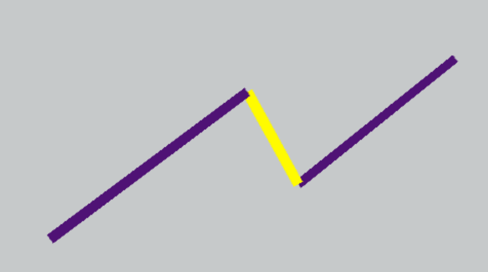
POINT-LINE SEGMENT



Given a point **Y** and a line segment $\boldsymbol{L(t)} = P + t\vec{v}$,

$$\boldsymbol{Closest\ Distance}: \begin{cases} \|Y - P\|, & if\ t' \leq 0 \\ \left\|Y - (P + t'\overrightarrow{v})\right\|, & if\ 0 < t' < 1 \\ \left\|Y - (P + \overrightarrow{v})\right\|, & if\ t' \geq 1 \end{cases}$$

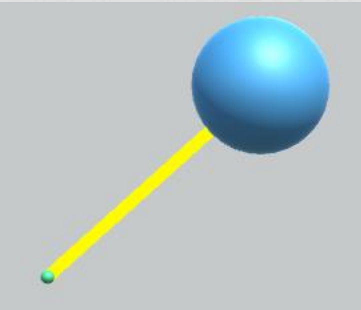
LINE SEGMENT-LINE SEGMENT



Given two parallel line segments $\boldsymbol{L_i(t)} = P_i + t\vec{d}_i$ $(i = 0{,}1,$ andt $t \in [0, T_i])$ and $\vec{\Delta} = P_0 - P_1$,

$$\textbf{\textit{Closest Distance}}: \begin{cases} \|\vec{\Delta}\|, \vec{d}_0.\vec{d}_1 < 0 \ \wedge \vec{d}_0.\vec{\Delta} \geq 0 \\ \left\|\vec{\Delta} + T_0\vec{d}_0\right\|, \vec{d}_0.\vec{d}_1 < 0 \ \wedge \vec{d}_0.(\vec{\Delta} + T_0\vec{d}_0) \geq 0 \\ \left\|\vec{\Delta} - T_1\vec{d}_1\right\|, \vec{d}_0.\vec{d}_1 < 0 \ \wedge \vec{d}_0.(\vec{\Delta} - T_1\vec{d}_1) \geq 0 \\ \ldots * \end{cases}$$

POINT-CIRCLE/SPHERE



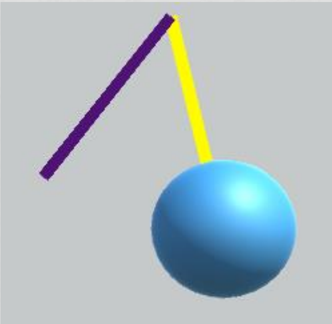
Given a points $\mathbf{P_1}$, the sphere's center $\mathbf{P_2}$ and the sphere's radius $\mathbf{r_1}$,

$$\textbf{\textit{Closest Distance}}: \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} - r_1$$

$$\textbf{\textit{Proximity Query}}: \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \leq r_1$$

*Too many cases to display.

LINE SEGMENT-CIRCLE/SPHERE



Given the sphere's center **Y**, the sphere's radius **r** and a line segment $\boldsymbol{L(t)} = P + t\vec{v}$,

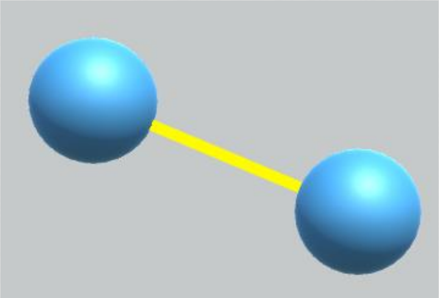
$$\boldsymbol{Closest\ Distance}: \begin{cases} \|Y - P\| - r, & if\ t' \leq 0 \\ \left\|Y - (P + t'\overrightarrow{v})\right\| - r, & if\ 0 < t' < 1 \\ \left\|Y - (P + \overrightarrow{v})\right\| - r, & if\ t' \geq 1 \end{cases}$$

CIRCLE/SPHERE-CIRCLE/SPHERE

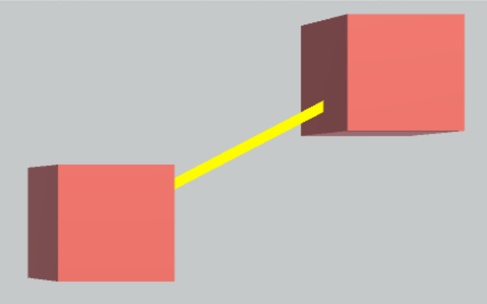
Given the sphere's centers $\mathbf{P_1}$ and $\mathbf{P_2}$ and the spheres' radii $\mathbf{r_1}$ and $\mathbf{r_2}$,

$$\boldsymbol{Closest\ Distance}: \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} - r_1 - r_2$$

$$\boldsymbol{Proximity\ Query}: \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \leq (r_1 + r_2)$$



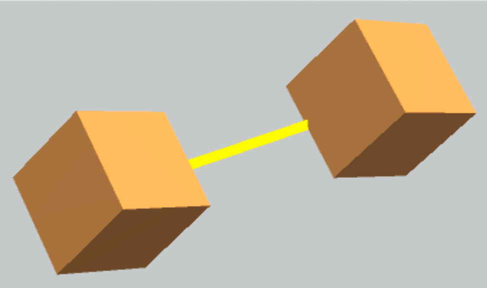
AABB-AABB



Given two AABBs **A** and **B**,

$$\textbf{Proximity Query}: \begin{cases} (A_{min_x} \le B_{max_x}) \wedge (B_{min_x} \le A_{max_x}) \\ (A_{min_y} \le B_{max_y}) \wedge (B_{min_y} \le A_{max_y}) \\ (A_{min_z} \le B_{max_z}) \wedge (B_{min_z} \le A_{max_z}) \end{cases}$$

OBB-OBB

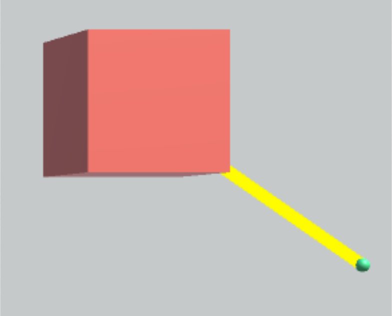


Given two OBBs, **A** and **B**, the vector joining their centers $\boldsymbol{d_{AB}}$, the boxes' extents $\mathbf{h_A}$ and $\mathbf{h_B}$ and a chosen separation axis, $\boldsymbol{L}$. Then,

$t = \|d_{AB} \cdot L\| - (\|h_A \cdot L\| + \|h_B \cdot L\|)$,

$$\textbf{Proximity Query}: \begin{cases} \exists L, t < 0 \Rightarrow No\ collision \\ \forall L, t \ge 0 \Rightarrow Collision \end{cases}$$

POINT-AABB



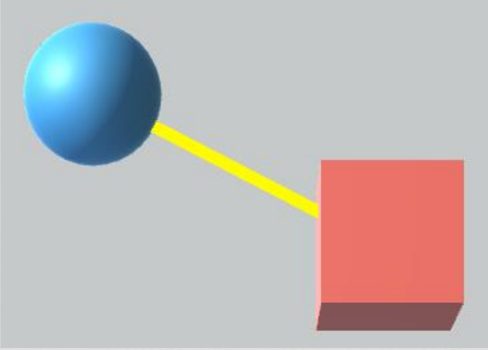
Given an AABB **A** and a point **P**,

$$\textbf{\textit{Proximity Query}}: \begin{cases} \left(P_x \le A_{max_x}\right) \wedge \left(A_{min_x} \le P_x\right) \\ \left(P_y \le A_{max_y}\right) \wedge \left(A_{min_y} \le P_y\right) \\ \left(P_z \le A_{max_z}\right) \wedge \left(A_{min_z} \le P_z\right) \end{cases}$$

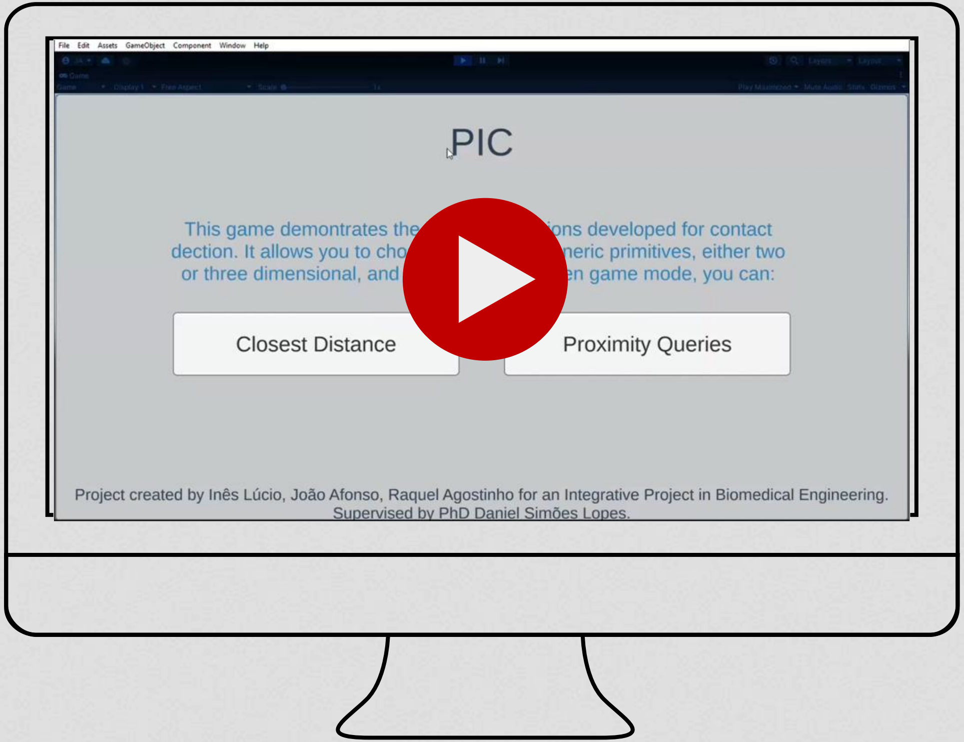
AABB-SPHERE

Given the AABB's closest point $\mathbf{P_1}$, the sphere's center $\mathbf{P_2}$ and sphere's radius $\mathbf{r_1}$,

$$\textbf{\textit{Proximity Query}}: \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \le r_1$$



UNITY MICROGRAME

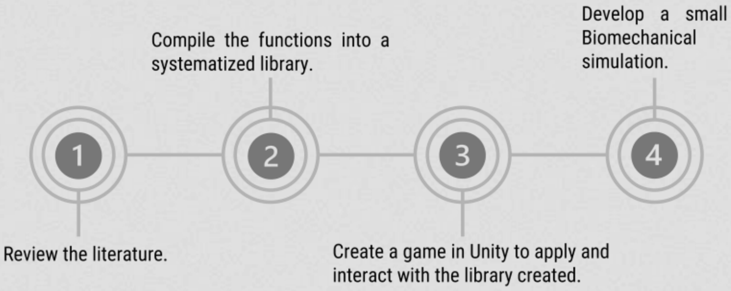


Link do vídeo: https://drive.google.com/file/d/1I-nE8S6uGAVRq8b31mflfXyv-chxXtKr/view?usp=sharing

ROBOTIC FOOT ON GROUND SIMULATION

Link do vídeo: https://drive.google.com/file/d/1sr5nXxCLY2mzsjYVgWBs8syQ7CCJ48qp/view?usp=sharing

FINAL REMARKS



All four of the goals completed

Work strategy followed through with the exeption of Step 5

FINAL REMARKS

Anyone can use the libraries developed to perform calculations of their interest !

OTHER POSSIBLE SIMULATIONS

- Hand-object contact for rehabilitation applications;
- Handrails for sports;
- Biomechanical seat design evaluation;
- Drug packaging.

IN THE FUTURE

- Add more complex primitives;
- Scale the libraries to other programming languages;
- Publish our work and share it with the community.

PROJECT MEMBERS:

FOR MORE QUESTIONS PLEASE CONTACT US:

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